# Design of a low noise, wide band, active dipole antenna for a cosmic ray radiodetection experiment

D.Charrier[*1] and the CODALEMA collaboration[2]

[1] SUBATECH, IN2P3-CNRS, Université de Nantes, Ecole des Mines de Nantes; 4 rue Alfred Kastler, BP20722, 44307 Nantes, France
E-mail: didier.charrier@subatech.in2p3.fr

[2] LESIA, Observatoire de Paris-Meudon - Station de Radioastronomie de Nançay - LAL, IN2P3-CNRS/Université de Paris Sud Orsay - LPSC, IN2P3-CNRS/UJF/INPG Grenoble - ESEO, Angers - LAOB, INSU-CNRS Besançon - LPCE, SDU-CNRS Université d'Orléans, France; http://codalema.in2p3.fr

## Introduction

An active dipole antenna has been designed to measure transient electric field induced by ultra high energy cosmic rays for the CODALEMA experiment [1,2]. The main requirements for this detector, composed of a low noise preamplifier placed close to a dipole antenna, are a wide bandwidth ranging from 100 kHz to 100 MHz and a good sensitivity on the whole spectrum [3].

## The active antenna concept

A simplified electrical model of a dipole antenna is a voltage source $V_a$ in serial with the antenna impedance $Z_a$, composed of a capacitance $C_a$, an inductance $L_a$ and a radiation resistance $R_{rad}$. For frequencies well below resonance (up to 1/5 of the resonance frequency $f_0$), $Z_a$ becomes equivalent to a capacitance due to a drop of the radiation resistance when the frequency decreases. Two options are possible to create the active dipole antenna: if the antenna is loaded by a preamplifier whose input impedance is a capacitance $C_{in}$ (high input impedance), then a capacitive attenuator is obtained (see Fig. 1); if the antenna is loaded by a capacitive feedback preamplifier (low input impedance), then the transfer function is given by the ratio of the antenna capacitance on the feedback one. In both cases, the relationship between the voltage induced on the antenna $V_a$ and the preamplifier output voltage $V_{out}$ becomes independent of the frequency. The first solution was implemented.
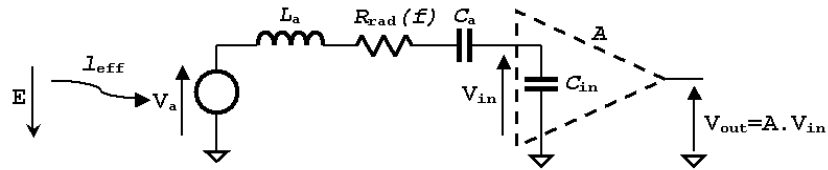


Figure 1: *Electrical equivalent model of the active antenna.*

In this scheme, the larger the antenna capacitance, the smaller the capacitive attenuation. One way to increase the antenna capacitance without decreasing $f_0$ is

to enlarge the antenna wire (fat dipole). In this configuration, the decrease of the antenna inductance lowers the Q-factor. Consequently, the antenna can be used nearer from its resonance frequency since its $V_{\text{out}}/V_{\text{a}}$ transfer function is flatter. Moreover the ohmic loss decreases when compared to a thin dipole.

## The antenna gain

The main advantage of a dipole antenna is an almost constant directivity for a very wide frequency band, providing that the antenna height is approximately less than two third of the shortest wavelength. A constant antenna gain $G(\theta, \varphi, f)$ assumes a lossless radiator and a perfect ground plane (infinite conductivity). A dipole antenna is also easy to build due to its simplicity: it is composed of two aluminium slats, each one sizing 0.6 m length by 0.1 m width, spaced by a gap of 10 mm and hold horizontally 1 m above the ground by a plastic mast. Assuming a perfect ground, simulations predict around 65° and 90° for the half power beam width of the E and H-plane respectively. The zenith gain is a roughly constant value of 8.5 dBi from 100 kHz to 50 MHz and decreases to 5.5 dBi at 100 MHz.

## The active antenna frequency response

The relationship between the preamplifier output voltage $V_{\text{out}}$ and a received electric field $E$ coming from the direction $(\theta, \varphi)$ and parallel to the antenna, where $l_{\text{eff}}$ is the antenna effective length[4] and $A$ is the preamplifier voltage gain, is given by:

$$\frac{V_{\text{out}}}{E} = l_{\text{eff}} \frac{V_{\text{out}}}{V_{\text{a}}} = \frac{c}{f} \sqrt{\frac{R_{\text{rad}}(f)G(\theta, \varphi, f)}{120\pi^2}} \times \frac{A}{1 + j2\pi Z_{\text{a}}(f)C_{\text{in}}f} \tag{1}$$

From the lowest frequencies up to $f_0/5$, the antenna can be considered as a short dipole without end-loading. Thus, the radiation resistance is $R_{\text{rad}} = 197(Lf/c)^2$ with $L$, the total antenna length [4]. Since $Z_{\text{a}}$ becomes equivalent to its capacitance $C_{\text{a}}$, Eq. 1 leads to:

$$\frac{V_{\text{out}}}{E} \simeq \frac{L}{\sqrt{6}} \sqrt{G(\theta, \varphi)} \times \frac{A}{1 + \frac{Cin}{Ca}} \tag{2}$$

Assuming a perfect ground plane Eq. 2 implies that $V_{\text{out}}/E$ is constant from 100 kHz to approximately $f_0/5$ in a given direction. At the zenith, effective lengths of $0.493\sqrt{G(\theta, \varphi)}$ =1.31 m for the low frequencies, and $0.628\sqrt{G(\theta, \varphi)}$ =1.19 m at 100 MHz, can be deduced.

The knowledge of the antenna impedance is very important. It has been measured with a vector network analyser supplying power to the antenna radiator through a 15 m cable and a balun RF transformer. The measured antenna capacitance (including parasitic capacitance) is 10 pF at 10 MHz and the resonance frequency is 112 MHz. With these values of $Z_{\text{a}}$, it becomes possible to calculate between 40 MHz and 170 MHz the $V_{\text{out}}/V_{\text{a}}$ transfer function of the antenna with its preamplifier. A simulation with accurate values of $R_{\text{rad}}$ from 100 kHz to 100 MHz is under study to plot the overall active antenna frequency response $V_{\text{out}}/E$.

# The preamplifier

To fulfil the noise and bandwidth constraints, a dedicated preamplifier was designed using the AMS BiCMOS $0.8\,\mu$ technology. This ASIC contains three fully differential amplifiers: the input one is low noise with a voltage gain of 33 dB and a capacitive input impedance of 10 pF. The gain of the middle amplifier is digitally adjustable from 9.5 to 16.8 dB. The power output amplifier is designed to drive a 100 $\Omega$ load. The maximum input dynamics is 24 mV and the consumption is 0.25 W. Because a low noise is required from the lowest frequencies and the antenna impedance is inversely proportional to the frequency, a MOS transistor was chosen due to its lack of current noise. The flicker noise is reduced choosing a P channel whereas the thermal noise is lowered by sizing a wide PMOS transistor. Since the widest the input transistor, the highest the input capacitance, there is one optimal size of the input CMOS transistor depending on the antenna capacitance. On the preamplifier output noise density measurement shown on Fig. 3, a dummy impedance equivalent to $Z_\mathrm{a}$ is connected to the differential input. This ASIC is mounted on a small printed board with a balun output transformer allowing to drive a 50 $\Omega$ load through a coaxial cable. The $V_\mathrm{out}/V_\mathrm{a}$ ratio of this preamplifier board (Fig. 2) is 30 dB with a 10 pF dummy antenna capacitance, and the -3 dB bandwidth is ranging from 80 kHz to 230 MHz. With the measured values of $Z_\mathrm{a}$, it exhibits a maximum value of 34.7 dB at 113 MHz due to the antenna resonance. Two external feedback resistors connect the differential outputs to the differential inputs to bias the preamplifier. Moreover, thanks to $C_\mathrm{in}$, they act as an active first order high pass filter whose cut off frequency can be easily adjusted from 10 kHz to more than 1 MHz.
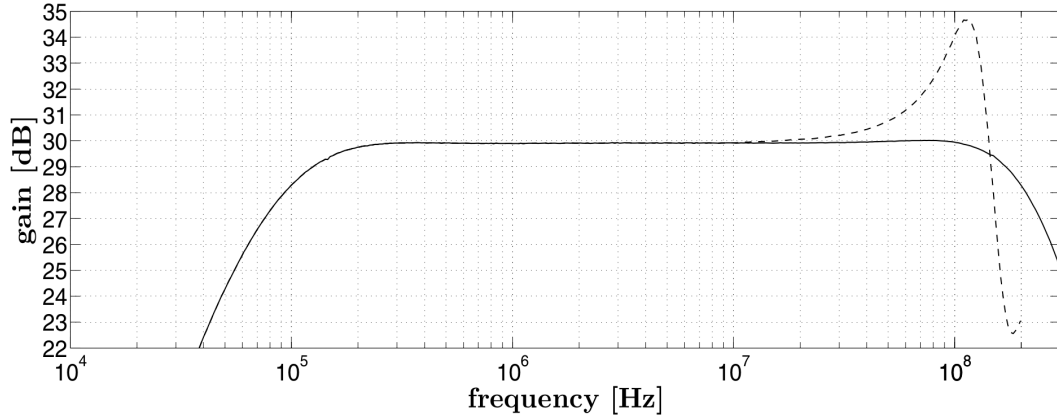


Figure 2: *Preamplifier gain measurements ($V_\mathrm{out}/V_\mathrm{a}$): the solid line is the measured gain replacing $Z_\mathrm{a}$ by a 10pF dummy antenna capacitance, whereas the dotted line is the gain calculated by taking into account the measured values of $Z_\mathrm{a}$.*

## The active antenna sensitivity

Two noise sources should be considered to evaluate the antenna sensitivity: the preamplifier electronic noise $v_{amp}^2$ which is mainly dominated by the first transistor stage, and the noise resulting from the sky background temperature $T_\mathrm{sky}$. It

generates an equivalent noise source $v^2_{sky} = 4k_\mathrm{B}T_\mathrm{sky}R_\mathrm{rad}$. The two noise densities shown on Fig. 3 are measured with the active antenna measuring the sky, and with the preamplifier whose input is connected to a dummy antenna impedance. Besides in the 5-30 MHz range, the sky noise floor is clearly greater than the preamplifier noise. The atmospheric noise seems to dominate below 5 MHz whereas the galactic noise is the greatest above 30 MHz. The $v^2_{sky}/v^2_{amp}$ ratio characterises the active antenna sensitivity: 0 dB at 50 MHz and 4.5 dB at 100 MHz. At 100 MHz, with a preamplifier gain of 34 dB (Fig. 2) and an output electronic noise of -131.7 dBm/Hz (Fig. 3), a galactic noise of -161.2 dBm/Hz at the preamplifier input can be deduced. With $R_\mathrm{rad} = 51.3\ \Omega$, $T_\mathrm{sky} = 1340K$ is calculated. The same calculation at 50 MHz, where $R_\mathrm{rad} = 5.3\ \Omega$ gives $T_\mathrm{sky} = 9480K$. These two temperature estimations agree fairly well with the known values [4]. One should note that those noises could be used as a calibration method for the CODALEMA experiment.
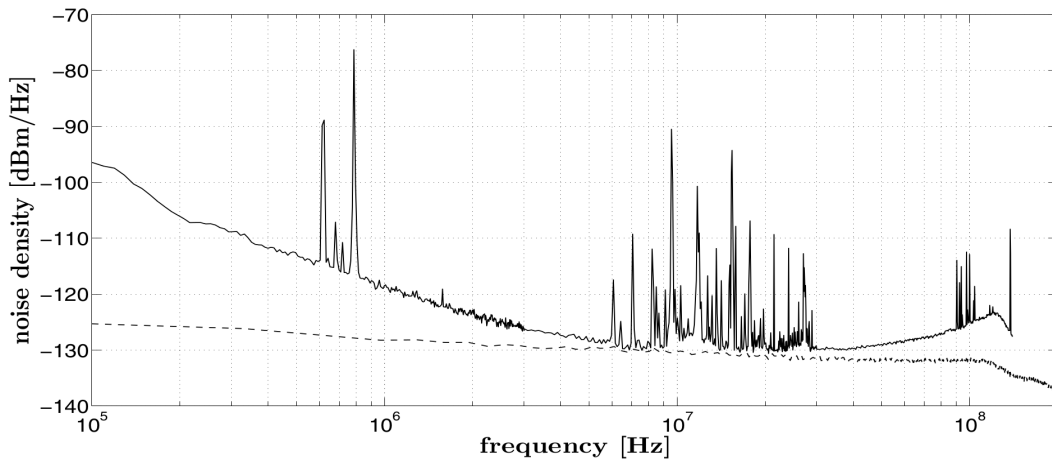


Figure 3: *Noise density measured with (solid line) the active antenna and a spectrum analyser at Malargue (Argentina) and without (dotted line) the antenna radiator.*

## Conclusion

This active antenna gives good results for its purpose. Since June 2005, a cross shape array of 16 antennas has been installed and is currently under operation at the Nançay radio-observatory. A new ASIC design with an up-to-date technology is under work from which an electronic noise improvement of 3 dB is expected.

## References

[1] D. Ardouin *et al.*, Nucl. Instruments and Methods, A 555 (2005) 148-163.

[2] D. Ardouin *et al.*, Astroparticle Physics, 26 (2006) 341-350.

[3] D. Ardouin *et al.*, Proc. X Pisa 2006 Meeting, Nucl. Instrum. Meth. A in press.

[4] J.D. Kraus, Antennas, McGraw-Hill, New York, 1988.